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Marine biofouling studies were conducted at Admiralty Inlet, Washington, during the period August 1963 to June 1968, in support of project VAMP. Thirty-nine species of biofoulers were collected and identified at the primary sampling station off Indian Island. Settlement of biofouling larvae was found to be minimal when water temperatures were below 10°C and in areas where strong currents were prevalent. In quiet waters, however, fouling organisms will add a 13-cm (5.1-in)-thick coating to

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) objects in the upper water column, and a 2.5-cm (1-in)- coating to bottom objects. Marine borer attack on wooden test panels was continuous throughout the year and most serious near the bottom; panels were destroyed in 6 months.

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FINAL REPORT ON MARINE BIOFOULING STUDIES AT ADMIRALTY INLET, WASHINGTON

JOHN R. DePALMA

APRIL 1976

NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON, D.C. 20373

FOREWORD

The Naval Oceanographic Office conducted a biofouling sampling program at Admiralty Inlet, Washington from August 1963 to June 1968 as a part of a series of biofouling studies. The kinds of biofouling organisms, their severity and season of attachment, distribution, and productivity are identified and related to marine operations.

J. E. AYRES
Captain, U.S. Navy
Commander

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INTRODUCTION

A study was made of the marine biofouling communities of Admiralty Inlet, Washington (fig. 1) during the period August 1963 to June 1968. This is one of a series of biofouling studies being made by the Naval Oceanographic Office (NAVOCEANO) at selected locations throughout the world to determine the character and extent of biofouling communities (fouling and boring organisms).

Specific objectives of these studies include collection of information on the kinds of attaching organisms, their season of attachment, areal distribution, and productivity. This information is then related to probable effects on marine hardware and instruments.

The office is grateful for the assistance of Dr. Victor Zullo of the University of North Carolina and Dr. Ruth Turner of the Harvard Museum of Comparative Zoology in identifying various specimens.

STUDY AREA

Admiralty Inlet, between Whidbey Island and the Olympic Peninsula of Washington (fig. 1), is the major approach to Puget Sound from the Strait of Juan de Fuca and the Pacific Ocean. This region is located within the Aleutian faunal province*, which extends from the Aleutian Chain to the Washington/Oregon border (Schenck and Keen, 1936).

The marine environment at Admiralty Inlet is typically coastal in character. Surface salinity values at the three exposure sites ranged from 29.4 ppt to 31.8 ppt (table 1). Transparency of the water is generally low due to a high spring and summer phytoplankton population and a high year-round suspended material content (Univ. of Washington, 1954). Based on our observations of attached algae on the test arrays the average annual compensation depth** appears to be about 10 or 11 m (32.8 or 36.1 ft). This depth, according to Storr (1964), is typical for coastal waters. Tidal currents exceeding 4 kn (206 cm/s) have been reported in the shallow, rather narrow inlet (USC&GS, 1965). Large-scale eddies generated by strong currents are associated with maximum tides (Univ. of Washington, 1975). Monthly sea surface temperatures at the exposure sites ranged from 57.5°F (14.2°C) in August to 44.5°F (6.9°C) in February, as shown in table 2.

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* Faunal provinces are coastal regions populated by more-or-less distinctive species.

** Compensation depth is the maximum depth of algal production.

METHODS OF COLLECTION AND ANALYSIS

The principal sampling station at Admiralty Inlet (designat l "Indian Island site," fig. 1) was located 0.1 mi (0.19 km) off I. .an Island. The water depth at mean low water (MLW) was 15 m (49.2 ft). Secondary sampling stations were at the sites designated "Port Townsend site" and "Marrowstone site" in figure 1. These were also approximately 0.1 mi (0.19 km) offshore and in 15 m (49.2 ft) of water.

Asbestos and pine wood panels, attached back-to-back, were used as collectors. These test panels were 15 cm (4.1 in) wide and 30 cm (8.2 in) long. At the Indian Island site the test panels were hung from buoyed arrays (fig. 2). On each of these arrays a test panel was exposed one m (3.3 ft) below the surface and another was exposed one m above the bottom. At the Port Townsend and Marrowstone exposure sites the test panels were hung from metal support racks, one m above the bottom. All test panels were hung vertically.

The Indian Island test panels were retrieved from the surface. The Port Townsend and Marrowstone test panels were retrieved by SCUBA divers.

At the Indian Island site, long term (designated as "series I") panels, exposed for one month and cumulatively longer periods to 12 months (and in one instance to 36 months), provided information on fouling rate, growth rate, and progressive changes in community development. Short term (designated as "series II") panels, exposed for consecutive monthly intervals, provided information on seasonal settlement of organisms.

Six special test panel arrays were exposed at the Indian Island site. These arrays were all exposed for 12 months, one each beginning in August, October, December, February, April, and June. These samplings were an attempt to determine the variation in fouling rate (weight per panel per year) for new substrates planted before, during, and after the season of maximum settlement and growth of most biofouling organisms. Since fouling rate is a function of recruitment plus growth, we wanted to see if one-year panels exposed at the beginning of the maximum growing period (April to September in northern waters) were <u>most</u> productive, if panels exposed at the end of this period were <u>least</u> productive, and if there would be a progression from each extreme. We also wanted to learn if there might also be changes in the dominant species, since early settlers on test panels are sometimes intraspecifically more competitive than later arrivals.

At the secondary sites (Port Townsend and Marrowstone), test panels were recovered only at 6-month and 12-month intervals, for comparison with similarly exposed panels from the Indian Island site.

After recovery the test panels and sometimes the polypropylene mooring lines were analyzed immediately or preserved in alcohol for future analysis. Test panel analysis consisted of identifying the various organisms, determining the size of the hardshelled forms, and estimating the percent of test panel surface covered by these foulers. The fouling material was then scraped from the asbestos panels and oven-dried at approximately 100°C (212°F) until the weight was constant. This dry weight value (g/450 cm^2/unit time) provided a measure of the biofouling productivity.

The mooring lines were examined to determine relative abundance and depth preferences for the various foulers. The degree of wood damage was determined by X-radiography.

Biofouling data sheets, dried biomass scrapings, X-radiographs, and a reference collection of specimens from test panels are filed under operation number 923001 at the Naval Oceanographic Office.

RESULTS AND DISCUSSION

Thirty-seven species of biofouling organisms were collected from series I and series II test panels at the Indian Island site. These are listed in table 3, with their year-to-year relative abundance.

Settlement of one or more species of foulers occurred throughout the year, but minimum numbers of animal foulers were present when water temperatures were below 50°F (10°C). This agrees with temperature tolerances of animal foulers observed by many other investigators.

The organisms that attached to mooring lines, floats, and test panels arranged themselves into two distinct assemblages - one near the surface and another near the bottom. The near-surface assemblage was dominated by either mussels, algae, or barnacles, depending on which species was most abundant at the time of exposure, or perhaps its ability to compete once attached. The near-bottom assemblage was always dominated by barnacles. Fouling on the mooring lines (mussels, algae, hydroids, tunicates, and tubeworms) tended to occur in clumps and clusters that diminished in size and frequency toward the bottom.

Dry weight data from series I bottom panels (table 4) showed a wide spread of values. The lack of a steady increase in weight is the result of occasional heavy grazing by predators (starfish, sea-urchins), which were common at the exposure sites.

Although the surface temperature and salinity records (tables 1 and 2) at the three sites in Admiralty Inlet were similar, the Marrowstone bottom fouling community turned out to be quite different from the bottom communities at the Indian Island and the Port Townsend sites. Test panels exposed at Marrowstone collected only trace amounts of encrusting bryozoans (Tubulipora) and coralline algae (Lithothamnion), whereas test panels from the other two sites collected substantial amounts of barnacles, bryozoans, and tubeworms. The likely explanation is that the Indian Island and Port Townsend sites were in quiet water, while the Marrowstone site was subjected to prolonged periods of strong currents and turbulence. Biofouling larvae settle with great difficulty at current speeds greater than 1.5 kn (77 cm/s), and newly settled larvae are torn loose from the substrate at current speeds greater than 3.5 kn (180 cm/s) (Doochin and Smith, 1951).

Test panels exposed at Indian Island for three years looked very much like those exposed for one year. The longer exposures merely produced more and somewhat larger specimens of the same species. The Indian Island community of foulers looked very much like those found along the east coast of the United States north of Cape Cod and along the coast of northern Europe. Many of the dominants at Indian Island were, in fact, the same circumpolar species found along the Atlantic coasts (Balanus crenatus, Mytilus edulis, Laminaria saccharina).

The results of the special series of one-year exposures at Indian Island were inconclusive, as can be seen in table 5. Seasonal effect, if any, was masked by the greater effect of variable settlement of the dominants near the surface and haphazard grazing by predators near the bottom.

Wooden test panels were attacked throughout the year by the large and very destructive molluscan borer, Bankia setacea. Panels near the bottom at Indian Island were most severely attacked, collecting more than 50 borers per panel in 6 months. The largest tunnel found in a 6-month panel measured 22 cm (8.7 in) in length and one cm (0.4 in) in diameter at the working end.

The crustacean borer Limnoria lignorum was less destructive than Bankia setacea at the three offshore exposure sites. Limnoria are poor swimmers and do not migrate far from their shoreline broodsites.

PRACTICAL APPLICATIONS

Animal foulers in Admiralty Inlet settle and grow mostly in spring and summer. In one year in quiet waters they can add a 13-cm (5.1-in)-thick coating to objects moored in the upper 12 m (39 ft) of the water column, and a 2.5-cm (1-in)-thick encrustation of hardshelled forms to bottom objects. In winter months large kelps may attach and by the end of summer they will have grown fronds as long as 6 m (20 ft). In exposed locations, turbulent water associated with strong tidal currents will tend to retard the settlement of both animals and plants.

Borers are a serious wood destroyer in this region. They were present in sufficient numbers at the Indian Island test site to have destroyed the bearing power of untreated marine pilings in one year*.

Antifouling protection of instruments and underwater hardware will be required at all depths in this region. Triphenyl lead acetate coatings will prevent settlement of both plant and animal foulers near the surface. Less expensive cuprous oxide coatings are recommended for mid-water and bottom objects. All wooden structures should be, at least, treated with creosote.

* Personal communication, Dr. Paul Trussell, British Columbia Research Corporation.

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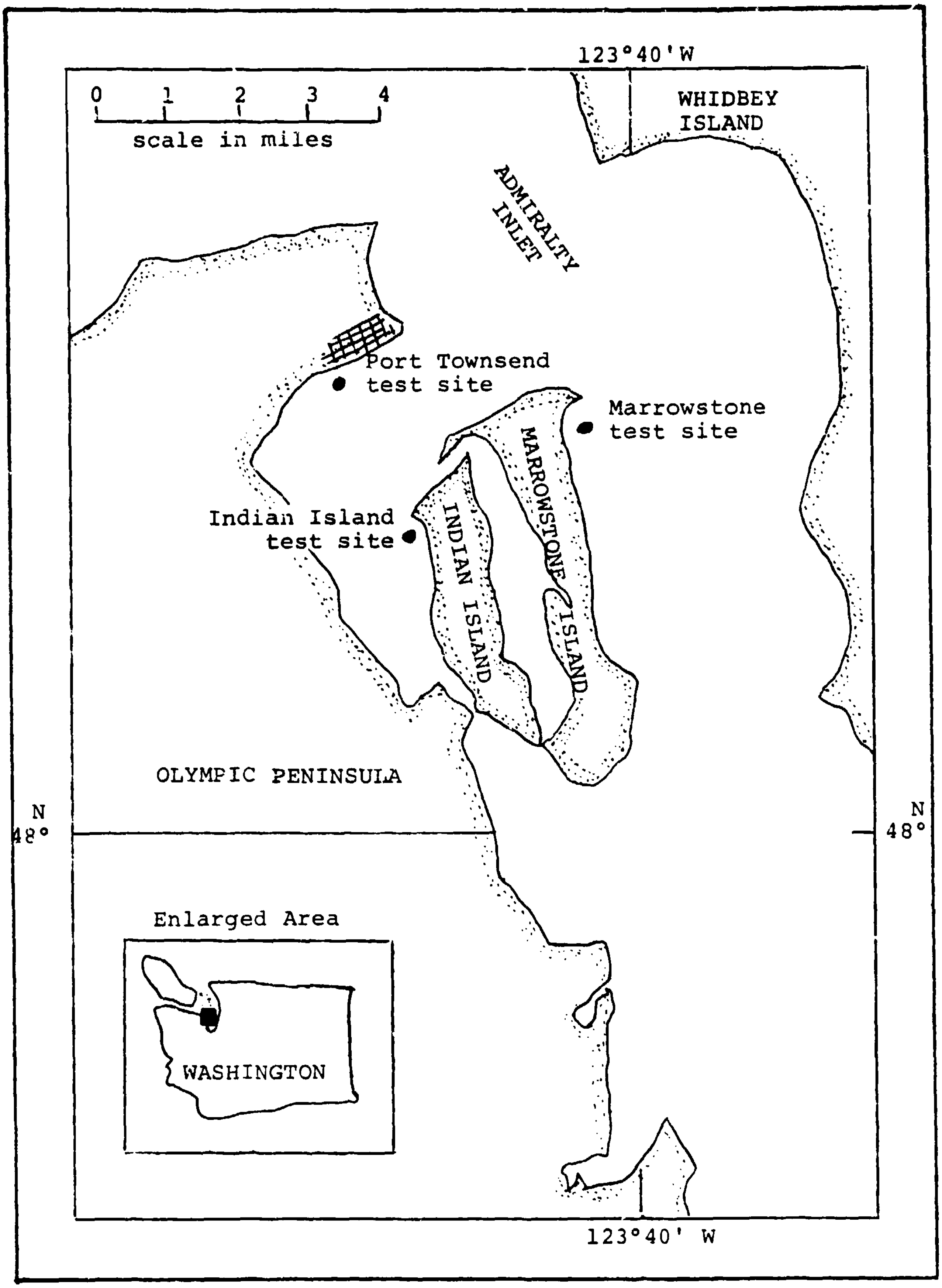

Figure 1. Admiralty Inlet Test Sites

MONTH	1963 Indian Island	1964 Indian Island	1965 Indian Island	1965 Port Townsend	1965 Marrowstone I.	1966 Indian Island	1966 Port Townsend	1966 Marrowstone I.	1967 Indian Island	1967 Port Townsend	1967 Marrowstone I.
January	-	30.5	29.6	-	-	29.9	30.4	30.2	30.0	29.9	30.1
February	-	29.7	29.5	29.4	-	30.2	30.4	30.0	30.0	29.8	30.1
March	-	29.7	29.4	-	-	29.8	30.2	30.4	-	-	-
April	-	30.1	30.4	30.4	-	30.0	30.2	29.5	30.2	30.0	30.2
May	-	30.3	29.9	30.3	-	29.8	29.8	29.5	30.1	30.5	-
June	-	-	30.6	30.2	-	30.4	30.8	29.7	30.2	-	30.4
July	-	30.1	30.5	30.6	-	30.4	30.8	30.5	-	-	-
August	30.6	-	30.9	30.8	30.6	30.3	30.8	30.2	30.4	-	-
September	31.8	30.5	31.2	31.8	31.2	31.0	31.8	31.2	-	-	-
October	31.1	30.6	31.2	31.4	30.9	30.9	31.1	31.3	-	-	-
November	31.1	30.6	31.0	31.0	31.0	30.5	30.4	30.6	-	-	-
December	30.5	30.1	30.3	30.4	30.4	29.7	30.7	29.8	-	-	-

Table 1. Surface salinity data ($^{o}/oo$) from Admiralty Inlet, Washington

MONTH	1963 Indian Island	1964 Indian Island	1965 Indian Island	1965 Port Townsend	1965 Marrowstone I.	1966 Indian Island	1966 Port Townsend	1966 Marrowstone I.	1967 Indian Island	1967 Port Townsend	1967 Marrowstone I.
January	-	30.5	29.6	-	-	29.9	30.4	30.2	30.0	29.9	30.1
February	-	29.7	29.5	29.4	-	30.2	30.4	30.0	30.0	29.8	30.1
March	-	29.7	29.4	-	-	29.8	30.2	30.4	-	-	-
April	-	30.1	30.4	30.4	-	30.0	30.2	29.5	30.2	30.0	30.2
May	-	30.3	29.9	30.3	-	29.8	29.8	29.5	30.1	30.5	-
June	-	-	30.6	30.2	-	30.4	30.8	29.7	30.2	-	30.4
July	-	30.1	30.5	30.6	-	30.4	30.8	30.5	-	-	-
August	30.6	-	30.9	30.8	30.6	30.3	30.8	30.2	30.4	-	-
September	31.8	30.5	31.2	31.8	31.2	31.0	31.8	31.2	-	-	-
October	31.1	30.6	31.2	31.4	30.9	30.9	31.1	31.3	-	-	-
November	31.1	30.6	31.0	31.0	31.0	30.5	30.4	30.6	-	-	-
December	30.5	30.1	30.3	30.4	30.4	29.7	30.7	29.8	-	-	-

Table 1. Surface salinity data ($^{o}/oo$) from Admiralty Inlet, Washington

MONTH	1963 Indian Island	1964 Indian Island	1964 Port Townsend	1965 Indian Island	1965 Port Townsend	1965 Marrowstone I.	1966 Indian Island	1966 Port Townsend	1966 Marrowstone I.	1967 Indian Island	1967 Port Townsend	1967 Marrowstone I.
January	-	7.5	-	8.3	7.2	-	7.5	8.3	7.8	8.6	8.3	9.3
February	-	7.1	-	6.9	7.2	-	7.5	7.5	7.7	8.3	8.1	7.8
March	-	8.9	-	8.1	-	-	9.2	10.0	8.6	7.6	7.8	7.8
April	-	7.8	-	8.3	7.8	-	10.0	10.0	9.2	8.9	9.2	8.7
May	-	10.8	-	11.1	-	-	10.6	10.6	9.4	10.6	10.8	11.1
June	-	13.3	-	11.4	-	-	11.1	10.0	10.0	11.1	-	11.1
July	-	12.2	-	12.5	11.9	-	12.8	11.7	11.7	-	-	-
August	13.9	13.9	-	14.2	13.9	-	12.2	12.3	12.3	13.9	-	-
September	11.9	12.2	11.7	11.7	11.7	11.1	11.7	11.7	11.1	-	-	-
October	11.4	12.5	11.1	10.6	10.6	10.6	10.9	10.8	10.6	-	-	-
November	9.4	10.3	8.9	10.0	10.0	-	9.7	9.4	9.4	-	-	-
December	8.9	8.3	8.6	8.6	8.6	8.3	8.9	8.9	8.7	-	-	-

Table 2. Surface temperature data (°C) from Admiralty Inlet, Washington

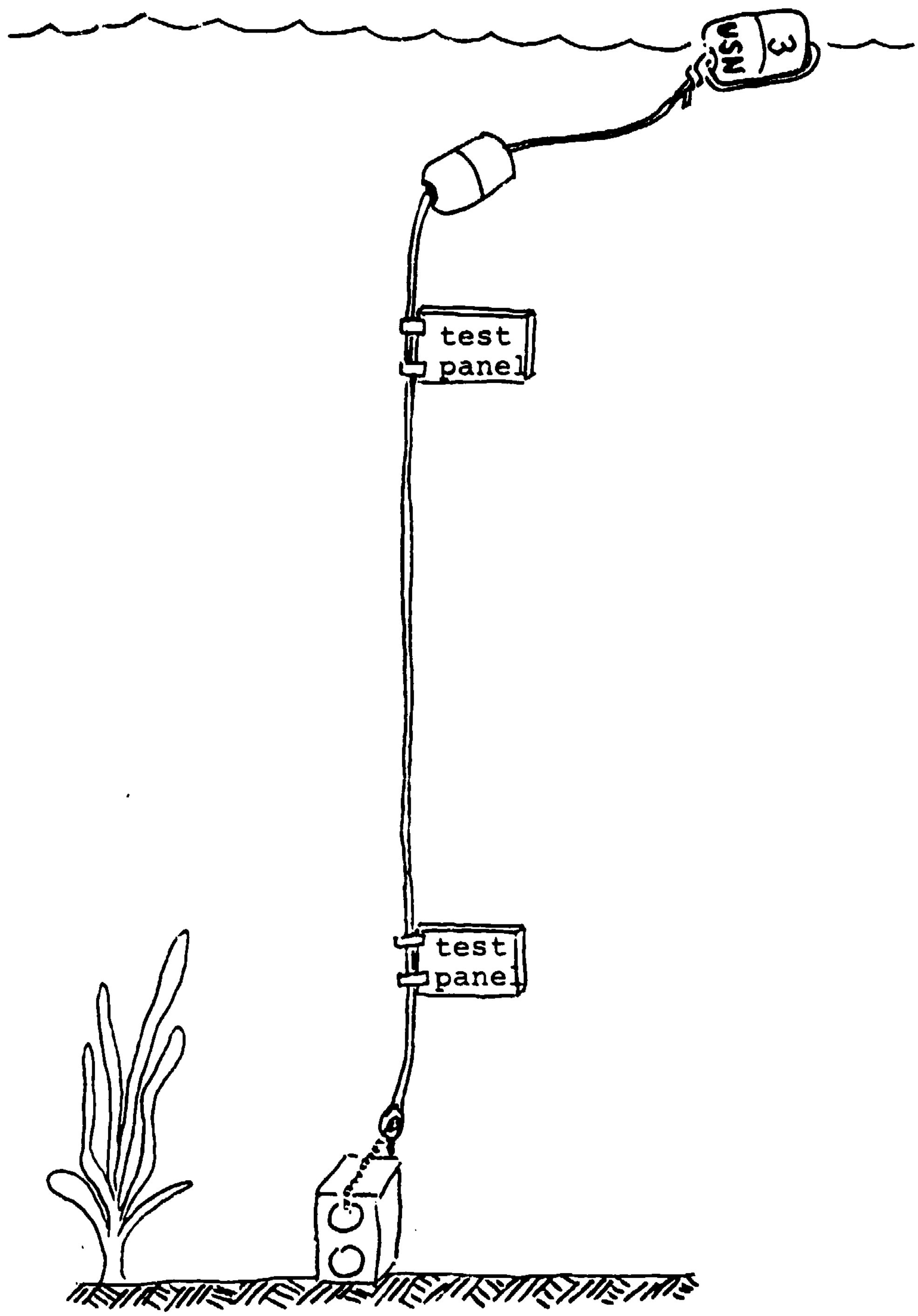

Figure 2. Marine biofouling test panel array

Organism	Local Abundance*							
	1st Yr		2nd Yr		3rd Yr		4th Yr	
	1 m	14m	1 m	14m	1 m	14m	1 m	14m
Algae:								
Ulva lactuca	xxx	-	xxx	-	xxx	-	xx	-
Nereocystis luetkeana	xx	-	-	-	xx	-	xxx	-
Macrocystis integrifolia	xx	-	x	-	x	-	x	-
Laminaria saccharina	x	-	xx	-	xx	-	x	-
Cladophora sp.	xxx	-	xxx	-	xx	-	xxx	-
Desmarestia munda	x	-	xx	-	xx	-	xx	-
Delessaria decipiens	x	-	xx	-	x	-	x	-
Porphyra variegata	x	-	x	-	x	-	-	-
Ceratium sp.	x	-	x	-	-	-	-	-
Costaria costata	x	-	x	-	x	-	x	-
Polysiphonia sp.	x	-	x	-	-	-	-	-
Heterochordaria abietina	x	-	-	-	-	-	-	-
Enteromorpha sp.	-	-	-	-	x	-	-	-
Coelenterata:								
Clytia sp	x	-	xx	x	xx	x	xx	-
Eudendrium sp.	x	-	x	x	x	x	x	x
Plumularia setacea	x	x	-	x	-	x	-	x
Epiactis prolifera	x	-	-	-	x	-	x	-
Bryozoa:								
Tubulipora flabellaris	xx	-	xx	-	x	-	xx	-
Hippothoa hyalina	x	xx	-	xx	-	xx	x	xx
Membranipora membranaceae	x	-	-	x	x	-	-	x
Microporella californica	-	x	-	-	-	x	-	x
Cribrilina annulata	-	-	-	-	-	x	-	-
Annelida:								
Pseudochitinopoma occidentalis	xx	xx	x	xx	xx	xx	x	xx
Serpula vermicularis	-	-	-	x	x	x	-	x
Spirorbis sp.	-	x	-	x	-	x	-	xx
Arthropoda:								
Balanus crenatus	xx	xxx	xx	xxx	xxx	xxx	xx	xxx
Balanus hesperius	xx	xx	xx	xx	xx	xx	xx	xx
Balanus cariosus	-	-	x	-	x	-	-	-
Limnoria lignorum	x[b]	xx[b]	x[b]	x[b]	x[b]	xx[b]	xx[b]	xx[b]
Mollusca:								
Bankia setacea	xx[b]	xx[b]	xx[b]	xx[b]	xx[b]	xx[b]	xx[b]	xx[b]
Mytilus edulis	xxx	-	xxx	-	xx	-	xxx	-
Pododesmus macroshisma	xx	xx	x	x	x	xx	xx	xx
Hiatella arctica	xx	-	xx	-	xx	-	xx	-
Tunicata:								
Pyura haustor	x	-	-	-	x	-	x	-
Styela tunicata	x	-	x	-	x	-	x	-
Chelyosoma productum	x	-	x	-	xx	-	x	-
Boltenia villosa	-	-	x	-	-	-	-	-

* xxx = Dominant; 40% or greater coverage on series I panels.
xx = Common; less than 40% coverage but occurs frequently.
x = Rare; never exceeds 1% coverage or occurs only rarely.
xx[b] = Marine borer; found consistently in series I wooden panels.
x[b] = Marine borer; found only rarely in series I wooden panels.

Table 3. Local abundance of biofouling organisms at the Indian Island test site

Months of Exposure	1st Year 1963-64	2d Year 1964-65	3d Year 1965-66	Cumulative 1964-67
1	1	2	-	
2	2	6	-	
3	-	10	-	
4	18	16	-	
5	76	19	1	
6	83	19	-	
7	74	4	1	
8	40	6	3	
9	21	17	31	
10	16	125	94	
11	-	-	67	
12	-	136	107	
36				140

Table 4. Rate of biofouling near the bottom at the Indian Island test site, Admiralty Inlet, Washington, expressed as g/450 cm^2/panel.

Dates	Panel * Depth (m)	Dry Weight (g/450 cm^2)	Dominant Foulers
Aug.'66-Aug.'67	1.5	65	*Mytilus* and algae
Oct.'66-Oct.'67	1.5	163	barnacles
Dec.'66-Dec.'67	1.5	287	barnacles and algae
Feb.'67-Feb.'68	1.5	594	barnacles and *Mytilus*
Apr.'67-Apr.'68	1.5	587	barnacles and *Mytilus*
Jun.'67-Jun.'68	1.5	151	*Mytilus*
Aug.'66-Aug.'67	13.5	4	barnacles
Oct.'66-Oct.'67	13.5	2	barnacles
Dec.'66-Dec.'67	13.5	16	barnacles
Feb.'67-Feb.'68	13.5	87	barnacles
Apr.'67-Apr.'68	13.5	93	barnacles
Jun.'67-Jun.'68	13.5	8	barnacles

* 1 m = 3.3 ft

Table 5. Biofouling rates for a special series of one-year test panels planted before, during, and after the season of maximum settlement and growth, Indian Island site, Admiralty Inlet, Washington.